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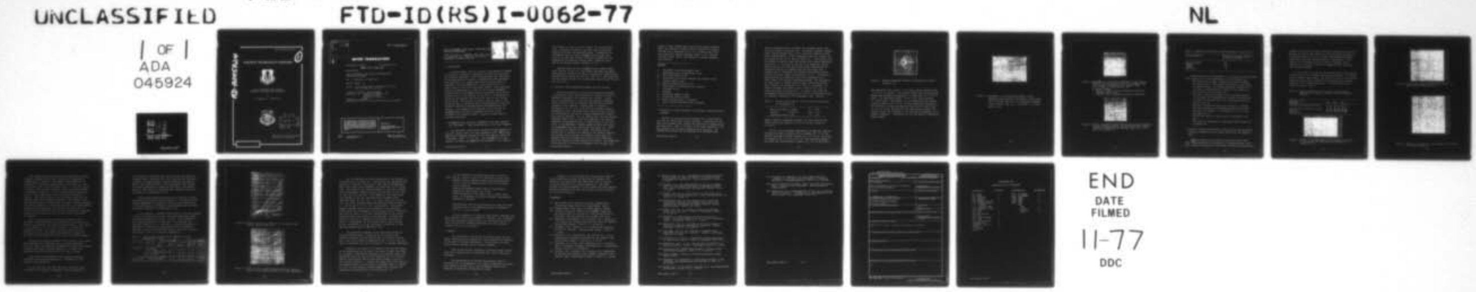

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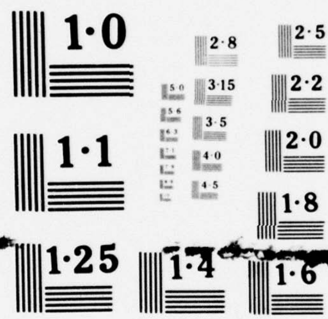
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FOREIGN TECHNOLOGY DIVISION

USE OF EXTREMELY HARD SOVIET
ABRASIVES FOR PRECISION MACHINING

by

F. Grünwald, G. Böswetter

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USE OF EXTREMELY HARD SOVIET ABRASIVES FOR PRECISION MACHINING

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0. Introduction

In recent years, the use of natural and synthetic diamonds in industrial production, especially in precision machining, has strongly increased. With the development and realization of the manufacture of synthetic diamonds and other extremely hard abrasives, for example cubic boron nitride (Elbor or Kubonite), the mass production in the Soviet Union of a whole series of tools has come under control, that previously could be manufactured only from or with natural diamonds. Considering this development and the increased use of Soviet diamond tools in the industry of the DDR, it is necessary to follow up and evaluate the use of this type of tool in the Soviet Union. The following reports, with the help of the evaluated Soviet literature and the documentation of the SAG "Elbor-R" (VEB Erste Maschinenfabrik Karl-Marx-Stadt [3]), should in this respect give a general view of the use of polyc~~h~~rystalline synthetic diamonds and tools of the extremely hard abrasive "Elbor", limited to some areas of precision machining.

1. Polyc~~h~~rystalline synthetic diamonds of the type "Ballas" and "Carbonado" - Cubic Boron Nitride of the type "Elbor-R"

The previously known Soviet synthetic diamond powders of fine and average grain size were expanded by new coa~~u~~rse polyc~~h~~rystalline diamond granules of the type "Ballas" (ASB) and "Carbonado" (ASPK) [1] [3] [19]. The granu~~la~~les of the type "Ballas" are dense, polyc~~h~~rystalline diamonds in the range of

size from 4 to 6 mm (0.4 to 0.7 carat) [6], with uniform fine crystalline structure, that are used for drawing, turning, drilling, and polishing tools. Diamonds of the "Carbonado" type are other polycrystalline forms that also are called upon instead of natural diamonds for the preparation of precision turning tools, dressing tools, and for polishing of metal surfaces [1] [2].

Besides these two new polycrystalline diamond types, since the end of 1971 [3], the further developed extremely hard material "Elbor-R" has been introduced for geometrically defined cutting tools [2] [14] [17] [18] [24]. The properties of cubic boron nitride have already been reported upon in [20] [21] [22] [23].

2. Synthetic Polycrystalline Diamonds for Wire Drawing

With the production of large polycrystalline diamonds of the "Ballas" type, the possibility of studying the use of synthetic diamonds in wire drawing was created. It was able to be determined in this way that synthetic diamonds of the "Ballas" type are suitable substitutes for natural diamonds in wire drawing. Drawing dies of "Ballas", according to [1] [2] [6] can be used for drawing tungsten, molybdenum, brass, and steel wires clad with brass, without the occurrence of any quality change compared with drawing with natural diamonds. In [2], drawing dies with die opening diameters from 0.12 to 0.3 mm are presented. For drawing tungsten and molybdenum wires, a drawing speed of 25 to 100 m/min. is recommended; a drawing speed of 400 to 800 m/min. is recommended for steel wires clad with brass [2]. Since drawing dies of "Ballas" are opaque, the drawn wire is called upon to estimate the quality of the drawing channel - the drawing stone orifices are formed by laser beam [6]. Surface quality and diameter of the wire give information about the condition of the drawing die orifice. The durability of drawing dies of synthetic diamonds of the "Ballas" type

equals or even exceeds that of dies from natural diamonds. Thus, the lifetime of drawing dies of "Ballas" in drawing tungsten wire, according to [1] is 1.5 times higher than that found with natural diamonds, while in [6], drawing stainless steel, 88% of the lifetime of natural diamonds was attained.

Symbols

a	Adjustment or cutting depth in mm.
F	Impression force in burnishing in kp
h_B	Wear index width in mm
R	Burnishing tool radius (diamond tip radius) in mm.
r	Cutting radius in mm
R_a	Median roughness value in μm
s	Feed advance in mm/revolution or mm/min.
T	Lifetime in min.
U	Rotation
v_G	Burnishing speed in m/min
v_s	Contouring speed in m/min
a	Front clearance angle in degrees
γ	Front cutting edge back rake in degrees

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3. Burnishing of Metal Surfaces with Synthetic Polycrystalline Diamonds

Single- or polycrystalline diamonds set in metal mounts are used for burnishing of metal surfaces. Burnishing of surfaces with diamond tools permits the machining of comparatively hard materials. This is a result of the great hardness of the tool material and its small coefficient of friction. The diamond tool slides over the surface to be burnished with

initial impression force, reshapes the roughness peaks, and fills the valleys with metal [1]. Currently, synthetic diamond tools (called diamond tips in [2]) are being offered by their Soviet manufacturers, of the "Carbonado" type, but results are also known of the use of "Ballas" tools [8]. The diamond tools are mounted in special types of holders that produce impression forces of F = 3 to 45 kp by the use of an adjustable spring. Special devices can also make possible the simultaneous but consecutive action of clamping tool and burnishing tool. Diamond tips of "Carbonado" can burnish heat-treated steels as well as bronze, brass, and aluminum [1] [2]. In addition, these diamond tips should be able to be sharpened two or three times on an ordinary sharpening grinder. The burnishing can take place on lathes, drill presses, and instructional drill presses with advances of s = 0.02 to 0.08 mm/rev. and working spindles with small runout (0.008 to 0.01 mm) in axial and radial directions [1]. In table 1 are given the recommended working conditions for the use of burnishing tools of synthetic diamonds of the "Carbonado" type. Figure 1

Table 1: Working Conditions for the Use of Burnishing Tools of "Carbonado" [2]

Burnishing speed in m/min.	40 ...100
Advance in mm/rev.	0.02... 0.07
Impression force in kp	10 ...25

shows a mounted "Carbonado" diamond; the tip radius can be chosen within the range of R = 0.5 to 4.0 mm in steps of 0.5 mm [2].

By the use of synthetic diamonds of the "Ballas" type for burnishing of steel surfaces with a hardness HRC > 60, the surface roughness (initial surface R_a = 0.2 to 0.32 μm) could be reduced to R_a = 0.05 to 0.16 μm. The burnishing speed in this case was varied within a range of v_G = 30 to 200 m/min.,

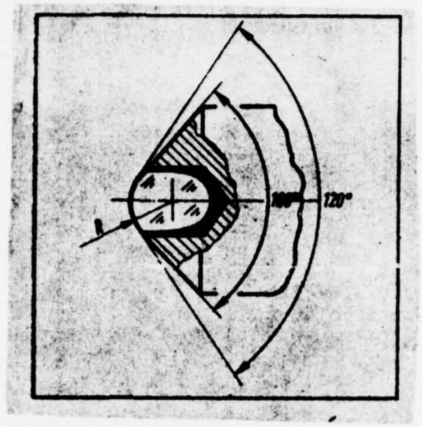

Figure 1: Mounted Carbonado Diamond for Burnishing of Metal Surfaces [2].

the impression force from F = 5 to 40 kp, and the advance from s = 0.04 to 0.1 mm/rev. The studies showed that the burnishing speeds were especially favorable in a range from v_G = 50 to 70 m/min., the impression force F = 20 to 25 kp, and an advance s = 0.047 m/rev. Furthermore, it was determined that diamond tips with radii of R = 2 to 2.5 mm are especially suitable for the machining of steel and similar materials with radii from R = 2.5 to 3.5 mm, and also for the burnishing of bronze [8]. Figure 2 shows the influence of the mentioned parameters on the surface roughness. "Industrial Oil 20" was used as lubricant in these studies.

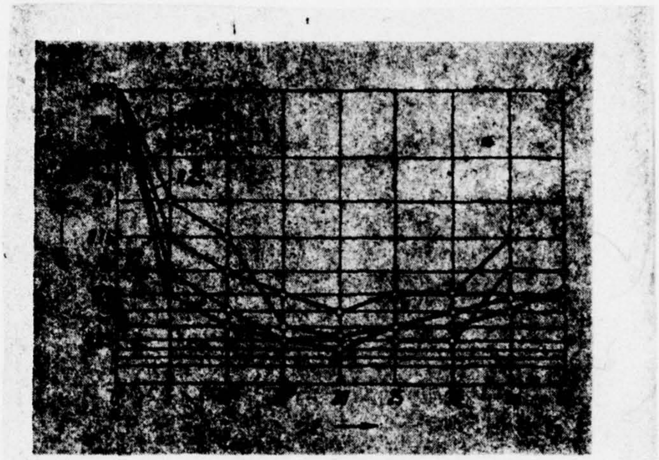

Figure 2: Dependence of the Surface Roughness on the impression force and the tip radius in burnishing steel 12 ChNZA, HRC 55-62 with synthetic diamonds of the "Ballas" type (v_G = 50 m/min., s = 0.047 mm/rev.) [8].

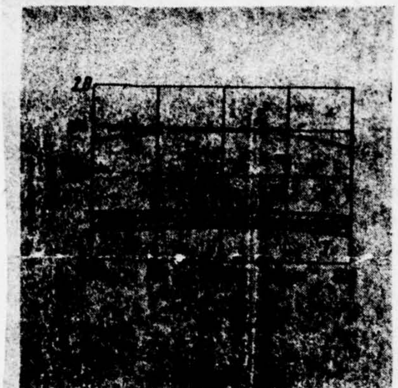

Figure 3: Dependence of the surface roughness on the cutting speed in the precision turning of non-ferrous metal with synthetic diamonds of the "Ballas" type (a = 0.2 mm, s = 0.02 mm/rev.) [4]

1. Natural diamond
2. "Ballas" tools, cutting surfaces not precision machined additionally
3. "Ballas" tools, especially precision machined

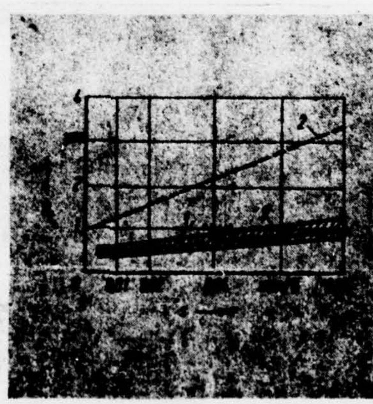

Figure 4: Effect of advance acceleration on the surface roughness in the precision turning of non-ferrous metal with synthetic diamonds of the "Ballas" type (v_s = 300 m/min, a = 0.2 mm) [4].

Table 2: Comparison of various cutting materials in drilling [7]

Cutting Material	Relative life time compared to natural diamond %
Natural Diamond	100
"Ballas"	73
Elbor	19
Hard Metal	4

Besides the quality improvement of the surface from burnishing with diamond tools, other advantages also are brought out:

- The tools have a higher lifetime than other customary burnishing tools. The useful path length in burnishing of hardened steel with optimum parameters amounts to 20 to 25 km; in the machining of bronze, the useful path path lengths are even higher [8].
- The micro and macro hardness of the machined material is increased, the hardened layer reaches thicknesses of 0.03 mm, and the total depth of the reshaped layer can amount to 0.1 mm.
- The wear of burnished work piece surfaces is reduced. The wear resistance of burnished running rails roller bearings, for example, is increased by 1.5- to 2-fold according to [1].
- The desired quality in most cases is obtained in one pass.
- The corrosion resistance of burnished steel surfaces is increased [9].

4. Precision Turning and Precision Drilling with Polycrystalline Synthetic Diamonds and Cubic Boron Nitride of the "Elbor-R" Type.

Studies carried out in plants of the Soviet Union show that cutting materials (for example, of high-speed steel, hard metal, abrasive ceramics) do not permit uniform and qualitatively

trouble-free precision turning under mass production conditions. Besides the use of ruby cutters for the precision machining of non-ferrous metals [11] [13], natural and synthetic diamonds especially offer true possibilities for improvements. With respect to an augmented use of synthetic diamonds, these results are of special interest in comparison with machining with natural diamonds.

In [4], parts of a special non-ferrous metal were precision turned with tools of "Ballas" and natural diamonds. One object of the studies, among others, was also the effect of the surface quality of the cutting surface of the diamond on the surface roughness of the turned work piece. The relationships are given in Figures 3 and 4.

Table 3: Working Conditions for the Use of Turning Tools Mounted with Synthetic Diamonds of the "Carbonado" Type [2].

Material to be Machined	v_s m/min	s mm/U	a mm
Fiberglass reinforced plastic	400 ... 600	0,04 ... 0,07	0,5 ... 1,0
silicon-rich non-ferrous alloys	300 ... 700	0,02 ... 0,07	0,1 ... 0,5
Ceramic	200 ... 300	0,04 ... 0,07	0,2 ... 0,5
Hard alloys	10 ... 30	0,02 ... 0,07	0,1 ... 0,15

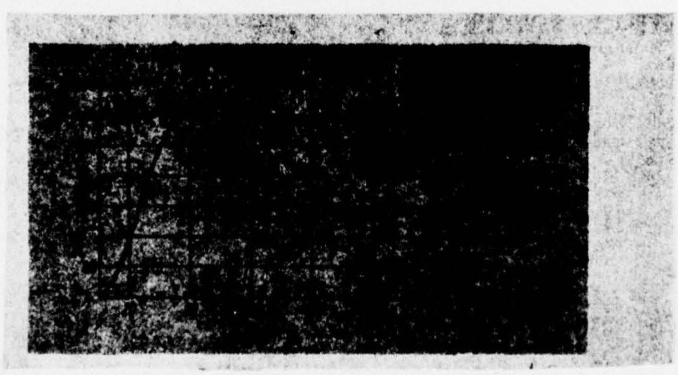

Figure 5: Effect of cutting speed on the lifetime in turning of high speed steel R18 with turning tools of "Elbor-R" [3].

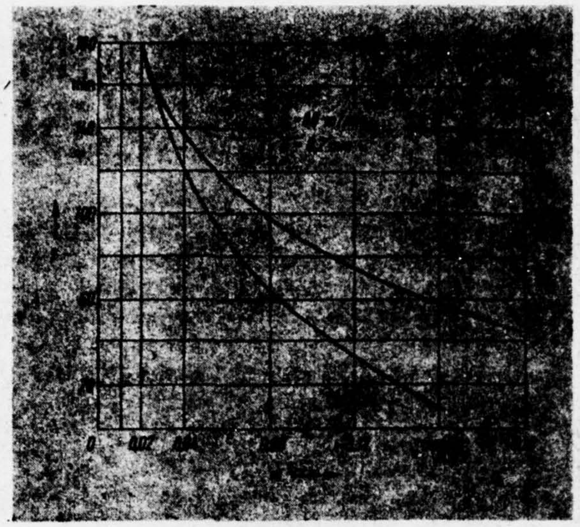

Figure 6: Relationship between lifetime and advance as a function of cutting radius [3].

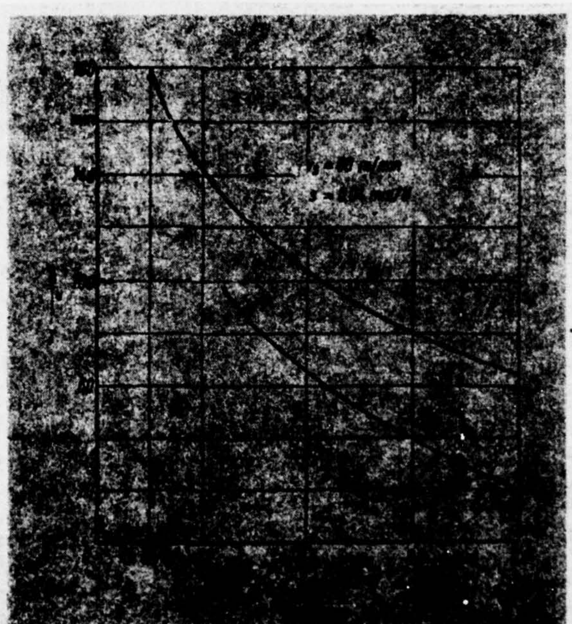

Figure 7: Effect of cut depth on the lifetime as a function of cutting radius [3].

The hatched areas show in each case the range of surface roughness produced by precision turning with sharpened or lapped tools of "Ballas." The studies also showed that a variation of the cutting speed within a range from $v_s = 200$ to 600 m/min. and of the cut depth from a = 0.1 to 0.5 mm has no effect on the surface roughness, while the feed does make a difference (Figure 4). It was also determined that cutter wear to a wear index width of 0.05 mm does not diminish quality. The results show that in precision turning of non-ferrous metals with synthetic diamonds of the "Ballas" type, surface qualities are obtained that are equal to those produced by natural diamonds, if the cutter geometry is optimized and the diamond cutters themselves are precision machined [4] [5]. It was also ascertained in [5] that even fiberglass reinforced plastics can be satisfactorily precision turned with tools of "Ballas."

In [7], various drilling tools with extremely hard synthetic cutting materials were studied for the machining of parts of an aluminum alloy under the conditions $v_s = 251$ m/min., s = 220 mm/min, and a = 0.05 to 0.06 mm., at a bore hole diameter of 50 mm. The results in table 2 show that only drilling tools that are mounted with synthetic diamonds of the "Ballas" type approach the efficiency of natural diamonds.

Besides the synthetic diamonds of the "Ballas" type, tools were prepared with "Carbonado" also, and were presented in [2] [24]. They are especially recommended for precision turning of non-ferrous metals and non-metallics. In table 3 the appropriate working conditions for this use are shown.

Along with the improvement of the surface quality by precision turning with diamond tools, a hardening of the surface is also obtained.

In [2] [12] [15] [16] [18] and [25], the use of tools of "Elbor-R" for turning is reported. Both the results in

[3] and Soviet experience show that with this new abrasive, hardened steel, unalloyed cast iron, high-alloyed centrifugal castings, chilled castings, aluminum castings, non-ferrous metals, and hardened metals can be machined by chip removal with high productivity, dimensional precision, and surface quality. The results of machining grey castings with tools of "Elbor-R" are reported in [15].

The durability and wear properties of "Elbor-R" turning tools and the attainable surface quality as a function of the process parameters in precision turning of high speed steel R 18 (corresponding to X74WV18.1) are exhibited with the help of figures 5 through 9 as described in [3].

In [3] moreover, detailed descriptions of the wear process in tools of "Elbor-R" are given, the permissible wear index range was ascertained to be $h_B = 0.4$ mm., and the effect of the chipping conditions is described. For hardened iron materials (HRC 62 ± 2), a lifetime of at least 80 minutes is obtained by observation of the proper cutting conditions. Therefore, the use of an "Elbor-R" turning tool runs to 480 to 640 minutes with 6 to 8 possible reshapings.

Table 4: Guide values for the use of "Elbor-R" turning procedures [3] [5].

Material to be machined	Turning operation to be carried out	technical settings: cutting speed v_s m/min	cut depth a mm	advance s mm/rev	obtainable quality: roughness depth R_t µm	precision class
hardened steel (HRC 40 ... 65)	rough machining (removal of the largest part of the machining excess	50 ... 120	0,8 ... 1,5	0,08 ... 0,16	10 ... 6,3	—
	smooth machining, inner and outer	80 ... 120	0,2 ... 0,6	0,04 ... 0,08	6,3 ... 3,2	2
	precision machining, inner & outer	80 ... 120	0,05 ... 0,2	0,02 ... 0,04	3,2 ... 1,6	1
grey castings, chilled castings	smooth machining inner & outer	300 ... 400	0,02 ... 1,0	0,02 ... 0,04	6,3 ... 3,2	—

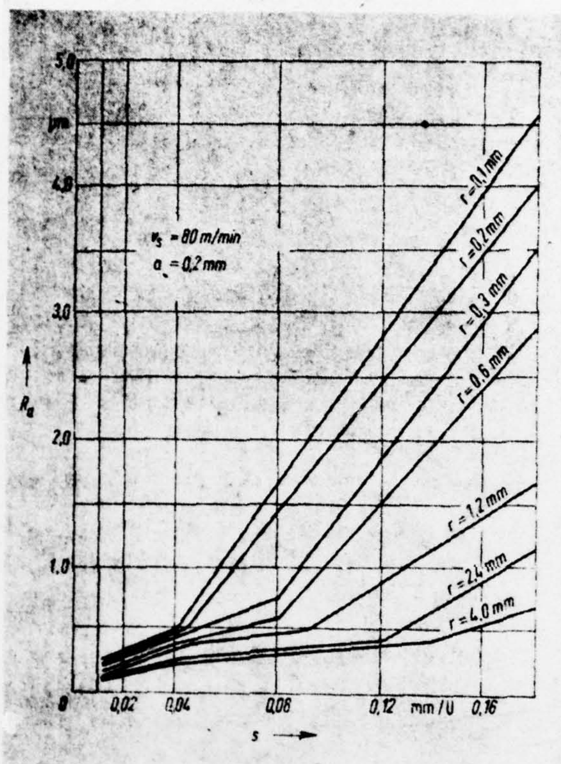

Figure 8: Sufrace quality as a function of the advance and various cutting radii [3].

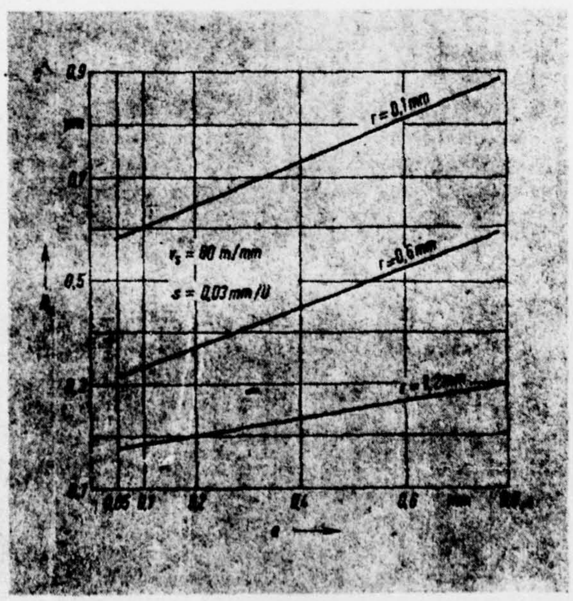

Figure 9: Effect of the cut depth together with the cutting radius on the surface quality [3] of the turned part.

For the machining of non-ferrous metals, the lifetime is estimated at 3 to 4 hours [3]. Instructions for regrinding and lapping of "Elbor-R" turning units (they can be reshaped more easily than large grain diamonds) are given both in [3] and in [18]. The effect of the cutting geometry on the tool lifetime and the attainable surface quality are also shown in [3], and in [12] [16] [18] and [25]. The studies of [16] reveal that the lifetime of the tool increases with increasing front clearance angle (a = 20...25°, γ = -20°), while in [12] and [18], the front clearance angle and the back rake are given as a = 6 to 8° and γ = 0° or -10°, respectively. The cutting geometry depends directly on the material to be machined. Guide values for the geometry of the turning tools of "Elbor-R" are given in detail in [3] with consideration of the type of machining and of the material to be machined. Further guide values for the use of "Elbor-R" turning tools are given in table 4. Furthermore, at this point, mention might be made of the information in [3] on the studies carried out in the VEB First Machine Shop of ~~C~~Karl Marx City.

The obtainable roughness of the machined surfaces in turning hardened steels, influenced by the rigidity and vibration stability of the machine tool, the set-up, and the tool, lies in the order of magnitude of R_a = 1.25 to 0.16 μm, where in particular the rate of advance is of extreme importance.

Moreover, in figure 8, the effect of the cutting radius on the surface quality is shown. As figure 9 shows, the effect of cut depth on the surface roughness is relatively small, the magnitude of the cutting velocity according to [3] is of even smaller significance, and is particularly chosen in view of the lifetime (figure 5). Studies have shown that after turning the surface layers of work pieces of hardened steel to a depth of 50 to 70 μm, pressure stresses appear that increase the operational characteristics of the work piece [3].

In the following, the particulars from [3] will be given that set limits to the use of "Elbor-R" turning tools:

Maximum surface roughness before the Elbor machining $\leqq 120\ \mu m$ for an optimum useful life of the turning set of "Elbor-R"

-Holding the diameter-length ratio in rotationally symmetrical parts within 1:8 (1:10)

-Previous removal of the casting skin on steel, grey metal, and hardened cast parts, otherwise considerable decrease in lifetime.

-A preliminary limit for the machining of steel and steel castings occurs in the machining beyond a hardness of RC $\geqq 25$ or $\sigma_B > 90\ kp/mm^2$

In this connection it should be particularly observed that the economics of the use of "Elbor-R", "Ballas", and "Carbonado" tools are importantly determined by the increased cost of the tools, and an exact economic comparison with the customary turning tools is not available.

5. Summary

The evaluation of the Soviet literature shows that synthetic polycrystalline diamonds and tools mounted with "Elbor-R" can be used in precision machining. The efficiency of these tools equals or exceeds that of natural diamonds.

This review and the information contained therein should serve as a stimulus and an orientation for a use of the tools discussed.

The documentation of the VEB First Machine Shop of Carl Marx City is recommended [3] to those interested in turning with "Elbor-R" turning tools, since important details and examples of machining are spelled out there.

Finally, it can be stated that particularly "Elbor-R" tools significantly widen the machining of hardened iron materials that previously were machinable only by grinding or electro-erosivally or electro-chemically, they make possible the heat treatment of steels before the chip-removing machining operation, and they can partially replace grinding by turning or drilling.

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